Simplified Programming Design Based on Automatic Test System of Aeroengine

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Abstract: Aeroengine is a kind of highly complex and repairable multi-component system, which operates over a long time under the harsh conditions of high temperature, high pressure, high speed and high load, and any fault threatens the safety of the aircraft. Based on this, through the in-depth analysis of several common automatic fault detection methods used in aeroengines, an automatic test system based on association rules mining technology was proposed to realize automatic test of aeroengine fault. The system uses association rule mining algorithm to deal with the database with a large amount of data. By improving the algorithm, the improved algorithm can reduce the size of the database and the number of programming. The test results show that the hardware design of the automatic test system is reasonable, the signal acquisition is accurate and the error can meet the requirements; the design of the fault detection process is reasonable, the search algorithm is fast and accurate, the speed of detection is about twice as high as possible, and the service life of the engine is saved.

Keywords: aeroengine; automatic test system; association rules; Apriori algorithm

1. INTRODUCTION

Aeroengine is the core of the whole aircraft, and its performance has a direct impact on the performance of the aircraft. Aeroengine is the heart of an aircraft. As the control center of the engine, the importance of the electronic regulator is self-evident. At present, the development of engine controller and test system is developing in the direction of digitalization and automation [1]. Automatic test system is an instrument which can make the measured device automatically measure, diagnose, process, store, transmit, and display or output the test results in an appropriate way [2]. At present, the manual inspection table is used to detect the engine by manual method. The detection operation of this method is complex, the fault location is difficult, and the requirement for the operator is high. At the same time, because of the complex environment of the controller detection, there are many other high-power communication, radar, and guidance equipment in the vicinity. The existing equipment can't meet the complex and bad electromagnetic environment [3].

With the use of modern microelectronics and computer technology, the complexity of aeroengine controller is increasing. The traditional manual way of testing has been unable to meet the requirements. Combined with bus technology, virtual instrument technology, AI technology and information technology, modern automatic test equipment has become an effective guarantee for completing the test task of controller [4]. Therefore, it is very important to build an automatic detection system with data analysis and fault location function to liberate manpower, improve work efficiency and increase the stability and reliability of detection work [5].

2. STATE OF THE ART

Abroad has been the leader in the field of automatic testing. Since the middle of the 80s, the US military has begun to develop a general automated test system consisting of reusable public testing resources for a variety of weapon platforms and systems [6]. At present, the US Army has formed a series of universal automatic test system for the internal military. The navy integrated automatic support system and the third echelon test system for the Marine Corps have been widely used. The integrated automatic support system is the largest automatic test system in the world at present, which is mainly used for 2 and 3 level testing [7]. The third echelon test system developed by MANTEC Company is a portable and universal automatic test system for the maintenance of field weapons system by the US Marine Corps, and it has good maneuverability and is able to diagnose for analog, digital and RF circuits [8].

The research and development of automatic test system in China has been following the trend of foreign countries. Many domestic airlines have developed an automatic test platform with high level of information and high test efficiency [9]. At present, the development technology of automatic test system in China is relatively late, and there is a big gap, which is mainly manifested in: firstly, the standard in the field of automatic testing is designated by foreign countries, and the development of ATS can only follow the foreign standards, and the development cost is high; secondly, the development of automatic test system is lack of unified planning, the product standards of various domestic companies and units are different, and the generality is poor [10].

3. Automatic test system modeling of aircraft engine

3.1 The significance of automatic test system for aeroengine

Aeroengine is usually in the harsh and complex working environment of high temperature and high pressure, and the fault occurs frequently, which makes up a large ratio of the whole flight system fault. Therefore, it is of great significance to study the automatic detection technology of aeroengine and improve the level of fault detection. The fault diagnosis and isolation of the air component of the aeroengine plays an important role in the safe flight of the aircraft. The accurate and timely detection and isolation of faults can avoid some significant losses. As shown in Figure 1, the staff are manually testing the aeroengine. In recent years, great progress has been made in the research of aeroengine fault diagnosis, and many fault diagnosis algorithms with different structures and different platforms have emerged. At the same time, there are also some problems, such as the lack of original fault data in the stage of algorithm development, and it is difficult to make a direct comparison of the performance of different algorithms. The emergence of these problems has hindered the study of new fault diagnosis algorithms and the communication of existing fault diagnosis research results. The traditional fault diagnosis software and hardware simulation platform can only play the role of verification algorithm, but can't really solve the problem that the fault data is lack and the algorithm of diagnosis can't be compared horizontally.

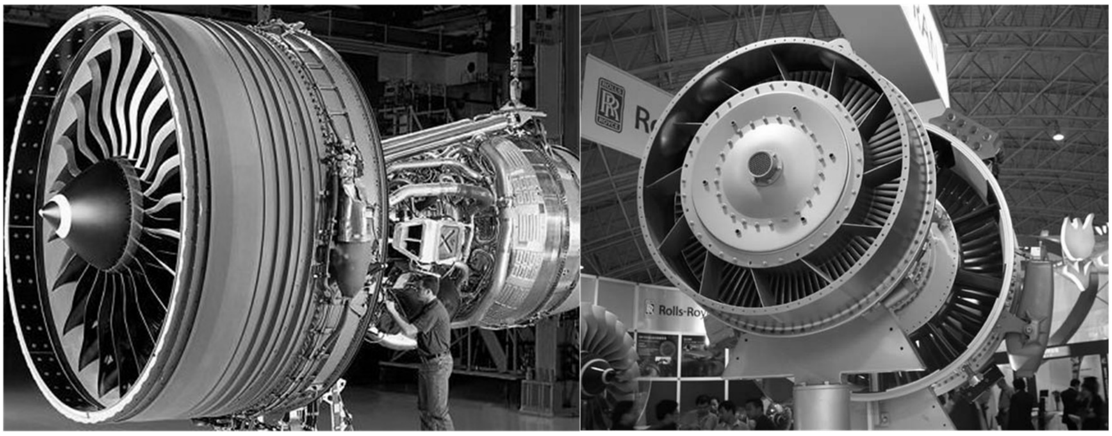

Fig.1 Aircraft engine fault detection

In traditional fault detection, the test data is usually compared with the data stored in the database, and then the fault is detected according to the result of comparison. There are unavoidable problems in traditional fault detection methods, such as too long training time and too many parameters. These problems will greatly reduce the practicality and effectiveness of the detection system, so that the detection effect is discounted.

3.2 Aeroengine fault detection process based on association rules

On the basis of fully studying association rule mining technology, automatic control system, aeroengine basic principle, aerospace flight system, fault detection technology and so on, and combined with the related characteristics of aeroengine, the basic flow of aeroengine fault detection is obtained by taking association rules as the core. The specific flow chart can be referred to Figure 2.

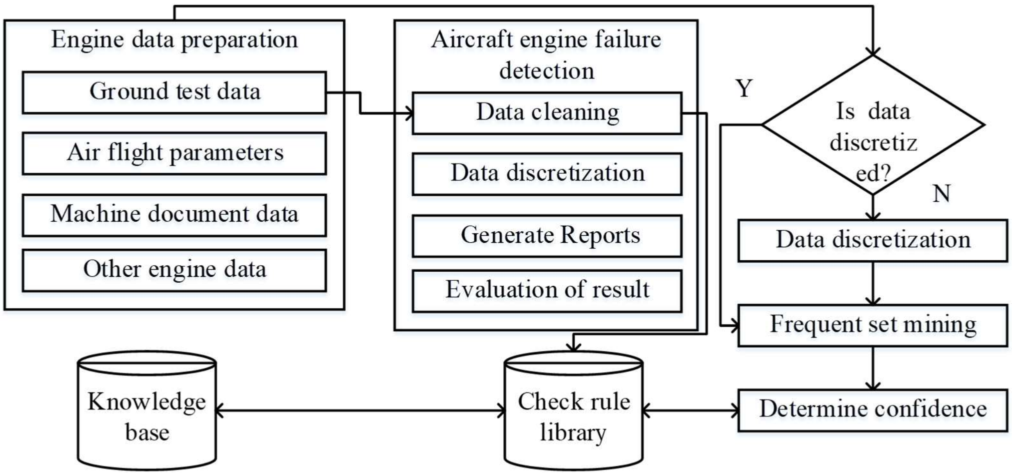

Fig.2 Aircraft engine fault detection process based on association rules

The data used in this study is derived from the parameters of the engine. The parameters of the engine are related to the basic characteristics of the engine. When the engine is in a state of normal work, the data will show a certain relevance. By making full use of these associations, the underlying principles of engine work can be excavated through parameter records. The correlation between these parameters will fail when the engine fails. On this basis, the engine can be detected in the fault.

3.3 Theory definition of Association Rules Mining Algorithm

Item and item set: the inseparable minimum unit information in a database is called a item, which is represented by a symbol i. The set of items is called an item set. Setting the set $I=\{i_1,i_2,\cdots,i_k\}$ is an item set, the number of items in the I is k, and the set I is called the k item set.

Affairs: setting $I=\{i_1,i_2,\cdots,i_k\}$ is a collection of all items in the database, a set of items contained in a single process is represented by T, $T=\{t_1,t_2,\cdots,t_n\}$. The item set contained in each t_i is a subset of I.

Association rules: association rules are the implication of shape like $X \Rightarrow Y$. Where X, Y are the proper subset of the I, and $X \cap Y = \varphi$. X is called the premise of the rule, and Y is called the result of the rule. The association rules reflect that when a item in X occurs, the rules of the item in the Y are also followed.

Support of association rules: the support degree of association rules is the ratio of the transaction number of X and Y to the number of all transactions in the transaction concentration, and it is recorded as support$(X \Rightarrow Y)$, that is, support $(X \Rightarrow Y)=$ support $X \cup Y = P(XY)$.

Support reflects the frequency that the items contained in X and Y appear at the same time in the transaction concentration.

Confidence of association rules: the confidence degree of the association rule is the ratio of the transaction number of X and Y in the transaction concentration to the number of all transactions and the number of transactions containing X, and it is recorded as confidence$(X \Rightarrow Y)$, namely:

$$\text{Confidence } (X \Rightarrow Y)=\frac{\sup port(X \cup Y)}{\sup port(X)}=P(Y|X) \quad (1)$$

Confidence reflects the conditional probability of the occurrence of Y in a transaction containing X.

Minimum support and minimum confidence: in order to achieve a certain requirement, a user needs to specify the threshold of support and confidence that the rules must satisfy. When support $(X \Rightarrow Y)$ and confidence $(X \Rightarrow Y)$ are more than and equal to their threshold values, it is believed that $X \Rightarrow Y$ is interesting, then these two values are called the minimum support degree threshold (min_sup) and the minimum confidence threshold (min_conf). In which, min_sup describes the minimum importance of association rules, and min_conf specifies the minimum reliability that the association rules must satisfy.

Strong association rules: support$(X \Rightarrow Y) \geq$ min_ sup and confidence$(X \Rightarrow Y) \geq$ min_ conf, the association rule $X \Rightarrow Y$ is called a strong association rule or $X \Rightarrow Y$ is called a weak association rule.

Setting X and Y are the item set in the data set D:

If $X \subseteq Y$, then support$(X) \geq$ support(Y); when $X \subseteq Y$, if X is a non frequent item set, then Y is also a non frequent item set, that is, the super set of any weak item set is a weak item set; when $X \subseteq Y$, if Y is an infrequent set of items, then X is also an infrequent set of items, that is, the subset of any large set of items is a large item set.

3.4 Improvement of frequent set mining algorithm Apriori

The basic principle of the Apriori algorithm is the calculation of the support degree of the item set. In the process of computing, the database needs to be processed, usually the database is scanned many times. In the process of scanning, if frequent item sets are found, which need to be recorded and the association rules are produced on the basis of the recorded data. In the first scanning, the set L_1 is obtained. When a data set is scanned in k ($k>1$) times, the results of the last scan are used, and the results of the previous scan are combined. The set C_k of the k (k>1) scan is obtained, and the support degree of the set C_k is determined. At the end of the scan, the set L_k of the frequent k set is calculated, and when the C_k is empty, the calculation process ends. The above discussion shows that if the improvement of the algorithm can be carried out from two angles, one is to reduce the size of the database, the other is to reduce the number of candidate set items.

The first step: in order to find L_k, a collection C_k of candidate k item set is generated by L_k-1 connecting with itself. Setting l_1 and l_2 are the set of items in L_k-1. $l_i[j]$ represents the j item of l_i. Apriori assumes that items in a affair or item set are sorted in a dictionary order. For (k-1) of item set l_i, it means sorting items, which makes $l_i[1] < l_i[2] < \ldots < l_i[k-1]$. If the previous ($k$-2) corresponding items of the elements l_1 and l_2 in L_k-1 are equal, then l_1 and l_2 can be connected, that is, if $(l_1[1]=l_2[1]) \cap (l_1[2]=l_2[2]) \cap \ldots \cap (l_1[k-2]=l_2[k-2]) \cap (l_1[k-1]<l_2[k-1])$, l_1 and l_2 can be connected. The condition $l_1[k-1] < l_2[k-1]$ can only guarantee no repetition. The result set generated by connecting l_1 and l_2 is $(l_1[1], l_1[2], \ldots, l_1[k-1], l_2[k-1])$.

The second step: the nature of the Apriori algorithm shows that any subset of frequent k item sets must be frequent item sets. The set C_k generated by the connection needs to be validated to remove the infrequent k item sets that do not meet the support degree.

3.5 Generation and test process of association rules for engine fault detection

Association rules are related to two factors, one is confidence and the other is minimum support. If these two factors are different, the association rules will also be different. The main role of confidence is to measure the credibility of the association rules, which is very important to the fault detection. If there is a mistake in the detection process, it will cause a lot of loss. Therefore, in the process of detection, the minimum confidence is usually chosen to be 1. According to certain rules, whether there is a failure can be judged.

The above rules are converted to: if the rotating speed of the high pressure rotor increases, the residual fuel instantaneous value is reduced; if the rotating speed of the low pressure rotor increases, the oil pressure increases; if the rotor speed of the low pressure rotor increases, the vibration value of the casing increases; if the gas temperature in the rear of the turbine is constant, the rotor speed of the low pressure rotor increases and the remaining instantaneous fuel oil is reduced; if the gas temperature behind the turbine is constant, the remaining instantaneous fuel oil value decreases and the oil pressure increases; if the gas temperature behind the turbine is constant, the remaining instantaneous fuel oil value is reduced and the oil pressure increases and the rotor speed of the low pressure rotor increases; if the gas temperature in the rear of the turbine is constant and the rotor speed of the low pressure rotor increases, the remaining instantaneous fuel value is reduced and the oil pressure increases; if the gas temperature of the turbine is constant and the oil pressure increases, the rotor speed of the low pressure rotor increases and the remaining instantaneous fuel oil is reduced.

In the process of testing, in addition to the connection of the relay and the determination of the discrete quantity, the simulation manual adjustment is the key point. In static and dynamic testing, the signal is automatically introduced to adjust the engine or controller to the location of the detection point: for example, T_1 and other signals need to be input in the static testing; T_2 is introduced in the dynamic detection, and the output of the temperature controller is adjusted to reduce the speed to the corresponding detection point. In view of this problem, a sequential incremental search algorithm is designed with 0.618 methods of single factor test, and the artificial adjustment process is simulated. The basic principle is to take the symmetry point of the first test point and the second test point within the scope of the test, that is, 0.382; experiments can be carried out in the above 2 points and the test results can be compared, the above mentioned methods are repeated within the retaining scope until the best value is found.

4. Analysis of examples

4.1 Experimental test results

The data used in this article is derived from the parameters of the engine. The parameters of these engines are related to the basic characteristics of the engine. When the engine is in a state of normal work, the data will show a certain relevance. By taking full advantage of these associations, the correlation between these parameters will fail when the engine fails. According to this, the fault detection of the engine can be realized. The test of the system was carried out in 2 steps on the test rig of an engine factory: the first was to test the accuracy of signal acquisition. Limited to the length, only the test results of T_1 are given, as shown in Table 1. The error of T_1 signal acquisition and measurement is within + 0.5 C, which can meet the requirements of engineering application.

Table.1 Test result of T_1

Given temperature($^\circ C$)	-100	-77	-50	-20	0	20	65	100
Collect temperature of T_1($^\circ C$)	-96.7	-76.5	-50.6	-20.8	-0.3	19.5	65.4	101.2

The second step was to verify the correctness of the software process and algorithm. This step connected the static and dynamic test for the engine. In order to verify whether the function and performance of the automatic tester meet the requirements of the design, the test was carried out. The test of automatic tester mainly included the hardware board level test, the hardware whole machine test and the software code test. In order to verify the reliability of the test function, a series of tests were carried out to verify the automatic test instrument.

4.2 Static test experiment for engine

In the static state, T_6 temperature was introduced to adjust the response of a controller so that the tachometer voltage and the excitation voltage were zero, at this time, the temperature of the collection tile should be within the range of 3-5°C of the maximum T_6 limit value, otherwise the temperature controller was not normal; in the static state, T_6 temperature was introduced to adjust the response of a controller so that the tachometer voltage and the excitation voltage were zero, the system automatically sent dead signals to the engine, and at the same time, it collected tile feedback signal and controller's nonlinear feedback response - excitation voltage and tachometer voltage signal, and the sampling interval was 0.1 s. The adjustment process of this section was extracted from the test results, as shown in Figure 3. The adjustment process was increased from 3 s to 778s, and the signal was gradually increased, and the precise adjustment process was from during 78s to 100s. After adjustment, the excitation voltage and tachometer voltage were 0.34V and 0.018V respectively, which satisfied the zero adjustment standard, and the search of the detection points was accurate, so that the artificial search process was simulated correctly.

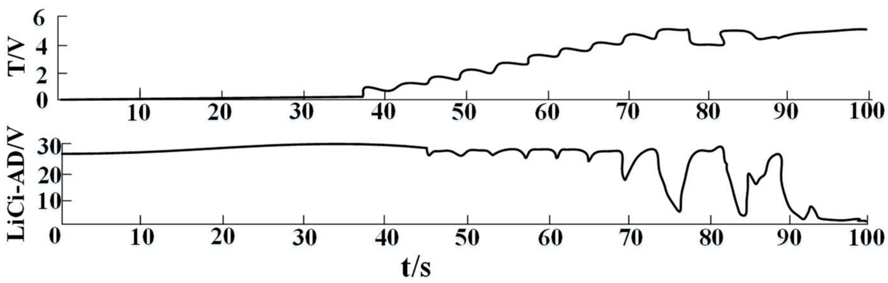

Fig.3 Change curve of the self-searching process

4.3 Dynamic test experiment for engine

In dynamic X_2 examination, T_6 temperature was introduced to adjust the response of a controller so that the tachometer voltage and the excitation voltage were zero, at this time, the location of the acquisition should be within the range of 1% of the design value, otherwise the engine was not normal. In the dynamic case, the test situation is shown in Figure 4. As can be seen from Figure 4, the rotor speed of the engine accurately followed the T_6 signal, and could quickly be reduced to the specified speed, and the value of X_2 was detected. In addition, the test system took only more than 20 minutes for completing dynamic and static testing. At present, the artificial detection takes more than 50 minutes, this method significantly improves the detection speed, which means shortening the engine ground start time and improving the service life of the engine.

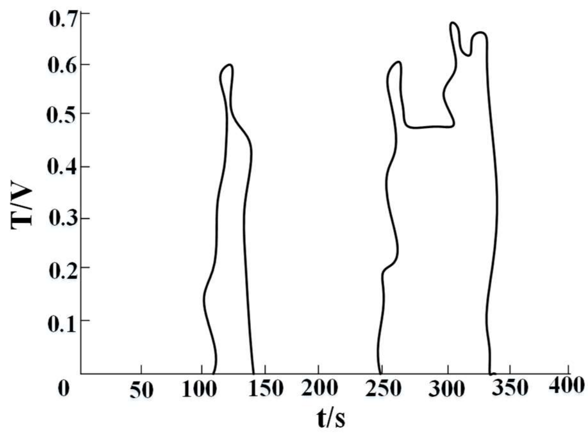

Fig.4 Examine of slowdown process by importing T_6

5. CONCLUSIONS

Aeroengine is the center of an aircraft engine. In order to ensure the normal operation of the engine in use, there is an extremely strict standard for the automatic detection of the engine running state. Therefore, the performance and the speed of the test system directly affect the performance of the engine fault detection, and even affect the safety of the aircraft. In order to ensure that the aeroengine is always able to work normally, the engine is required to be automatically tested and repaired. Traditional manual testing can't meet the increasingly complex testing requirements in testing efficiency and measurement accuracy. Based on this, an automatic test system for aeroengine based on association rule algorithm was proposed. By improving the classical mining frequent set algorithm Apriori in two aspects of reducing the scale of the database and reducing the number of candidate item sets, the optimization of classical mining algorithm was realized. The example shows that the improved algorithm is more efficient and succinct than the original algorithm. The improved mining process was applied to the actual training data, which generated feasible and effective fault detection rule for aeroengine; and then the rules were used to excavate the actual test data, and the results were in accordance with the actual situation. Therefore, it is feasible and effective to apply the association rules to the fault detection of the aeroengine. Finally, the automatic test system was designed for an aeroengine, and the automatic test was realized; the design of the whole structure and the key signal was reasonable, and the measurement of the long distance small signal was realized; the test software process was correct, and the manual adjustment process was simulated successfully with the 0.618 method, and the rapid determination of the detection point was realized. The test results show that the designed test system meets the actual engineering requirements, and the detection speed is increased by about one time.

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